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Aircraft Evacuations Onto Escape Slides and Platforms I: Effects of Passenger Motivation

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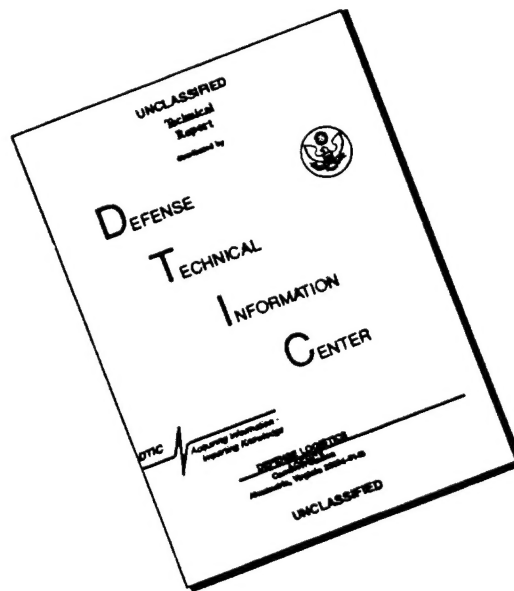


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16. Abstract <p>INTRODUCTION. Experimental evaluations of passenger egress during simulated emergency evacuations have provided different results, depending on such variables as subject motivation level and escape route utilized in the particular study. The study reported here was conducted to compare competitive versus cooperative subject behavior within a single study using inflatable escape slides versus door sill-height platforms connected to rigid ramps as the escape routes. METHODS. Four groups of subjects, ranging in age from 18 to 44, were employed in a 2 (motivation level) x 2 (egress route) x 2 (air quality) repeated-measures design. Motivation level was the between-groups factor; evacuation route and air quality (clear air versus smoke) were within-groups factors. RESULTS. Main effects on total egress time were found for motivation level ($p < .008$) and egress route ($p < .012$), as competitive behavior and platforms-with-ramps produced much faster evacuation times. Air quality effects on total egress times failed to achieve statistical significance; however, the combination of air quality with the other variables produced substantial interactions. CONCLUSION. These results indicate that findings derived from evacuation studies are very susceptible to nuances in individual subject behavior and experimental techniques/protocol. Combining previously studied independent variables may produce unexpected interactions that invalidate initial assumptions about the utility of those variables in answering specific research questions. Studies intended to assess the evacuation potential of aircraft designs, configurations, and operating procedures should tightly control such variables to prevent them from inadvertently confounding the experimental questions being addressed.</p>					
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AIRCRAFT EVACUATIONS ONTO ESCAPE SLIDES AND PLATFORMS

I: EFFECTS OF PASSENGER MOTIVATION

INTRODUCTION

Studies of simulated emergency aircraft evacuations are typically conducted to understand the effects of aircraft configurations, emergency equipment, crew procedures, or passenger attributes on egress. Examples may be found in a variety of relevant reports (Blethrow, Garner, Lowrey, Busby & Chandler, 1977; Pollard, Garner, Blethrow & Lowrey, 1978; McLean, Higgins & Lyne, 1989; McLean, Chittum, Funkhouser, Fairlie & Folk, 1992; McLean, George, Chittum & Funkhouser, 1995; McLean & George, 1995; Muir, Marrison & Evans, 1989; Muir, Bottomley & Hall, 1992; Rasmussen & Chittum, 1989). The results of these research studies are typically applied as guidance for changes in aircraft equipment and procedures, as well as to provide an understanding of the human factors considerations that impact emergency evacuations. Often, however, differences in experimental techniques among cabin safety research laboratories have produced differences in opinion about the utility of particular data resulting from these studies. The differences have led to divergence in the worldwide regulations promulgated by aviation regulatory authorities; such incongruities are troublesome to justify, and often complicate operations for air carriers flying internationally. In an attempt to resolve this dilemma, the Federal Aviation Administration and its international regulatory partners have begun harmonization efforts designed to identify which research techniques and resultant data provide the most logical basis for regulation of the aviation industry.

The study reported here was designed to support this process, studying the effects of

differences in passenger motivation on egress through floor-level Type-I transport category aircraft (airliner) doors onto: 1) a Boeing B-737 inflatable escape slide, and 2) doorsill-height platform scaffolding. Both means of egress were attached to the Civil Aeromedical Institute's (CAMI) aircraft cabin evacuation facility (ACEF), which was raised to a doorsill height of 8 feet, 9 inches above the ground.

The effects of egress route were in question because inflatable slides are the typical means for emergency egress from airliners, but previous studies sometimes made use of doorsill-height platforms (e.g., Muir et al, 1989). Further, a 1992 full-scale evacuation demonstration onto doorsill-height platforms was used to support a Code of Federal Regulations (CFR) § 25.803 analysis for certification of the MD-11 aircraft. Because of the platform use, the time allowed for successful completion of the demonstration was reduced from 90 to 62 seconds. This criterion was established by comparing passenger flow rates from prior unsuccessful MD-11 full-scale evacuation demonstrations with the flow rate established in evacuations conducted from a MD-11 sales mockup equipped with a platform. Since this has been the only full-scale evacuation demonstration to use platforms, the utility of the platform method would benefit from additional substantiation.

Passenger motivation levels were included because financial incentives had previously been used to mimic the panic thought to be important in emergency aircraft evacuations (Muir, et al., 1989;1992). The effects of financial incentives used in those studies were inconsistent across exit types, and were also at odds with results from similar studies using

Type-III exits, where motivation levels were manipulated through verbal instructions and flight attendant commands, instead of financial incentives (e.g., McLean, et al., 1995). Muir and her colleagues had also shown financial incentives to differentially affect egress through bulkhead openings leading to doors furnished with doorsill-height platforms with ramps (1989; 1992). These effects were modified when passenger visibility was impaired by theatrical smoke. As a result, interpreting and comparing the data from these independent activities had proven to be difficult; whether the effects held for floor level exits fitted with inflatable escape slides was not clear.

The present study was conducted to ascertain whether the apparent disparities among data arising from previous evacuation studies could be rendered comparable within a single paradigm, using a factorial research design. Use of the 2 egress routes was intended to answer questions about the willingness of passengers to deplane onto the different escape devices and how each route modeled actual evacuations. Experimental control of passenger motivation, using verbal instructions, flight attendant commands, and financial incentives, was included to compare the effects of resultant behavioral differences on egress. In addition to the direct motivational comparisons, this was also expected to provide enhanced assessment of the use of the 2 escape routes. Finally, the cabin interior was differentially maintained in both clear air and theatrical smoke during the series of evacuation trials to assess the effects of obscured vision on egress through floor-level exits, as well as to investigate the interaction of motivation level with ability to see.

It was hypothesized that egress onto the platform would be faster than that onto the inflatable escape slide, especially in clear air, as the doorsill-height platform was expected to produce no hindrance to egress, and smoke-

reduced visibility has generally produced severe reductions in egress speed (e.g., McLean, et al., 1989; Muir, et al., 1992). Effects of motivational condition were expected to be unevenly distributed across egress route, since competitive behavior was theorized to be more ardent when using the doorsill-height platform, as compared to the inflatable slide.

Assessments of these multiple treatments within a single laboratory (apparatus) and paradigm were meant to begin the normalization process of the aforementioned evacuation research data, to form a baseline for future evacuation research techniques and protocols, and to resolve questions of regulatory concern. A final intention was to establish state-of-the-art research designs and techniques that could be applied to both current and future aircraft evacuation systems and procedures.

METHODS

Subjects: The subjects acting as passengers in this experiment were 239 human adults between 18 and 44 years of age. The passengers were divided evenly among 4 experimental groups; each group contained 60 subjects apportioned equally by gender, except for group 3, which had only 59 subjects of which 61% were males. Table 1 provides the age ranges, weight ranges, and gender distribution for each group.

Table 1
Subject Attributes

GROUP	AGE	WEIGHT	GENDER	
			M	F
1	20-40	99-320	30	30
2	19-40	93-277	30	30
3	18-44	115-241	36	23
4	20-41	92-260	30	30
TOTALS			126	113

Subjects were also required to wear long-sleeved shirts and long pants, as well as low-heeled or flat shoes. Subjects were naive about, and had never participated in, aircraft evacuations.

Design: The research employed a 2 (egress route) X 2 (motivational level) X 2 (air quality) repeated-measures modified factorial design. Egress route (platform or slide) was counterbalanced across evacuation trials, providing 2 different trial orders. Two egress trials were conducted in clear air, followed by two egress trials in smoke, that replicated the trial order sequence used in clear air (Table 2). Although this research design biased against revealing any deleterious effects of smoke on egress, previous studies using smoke had shown robust reductions in egress speed (e.g., McLean, et al., 1989; Muir, et al., 1992), and the facilitatory effects of evacuation experience were not expected to confound the smoke effects. The last trial in clear air was designed to highlight individual decision-making, as each subject was allowed to choose his/her own egress route.

Table 2
Experimental Design

Group	Clear Air	Smoke	Clear Air
1	PLC SLC	PLO SLO	S/P
2	SLC PLC	SLO PLO	S/P
3	PHC SHC	PHO SHO	S/P
4	SHC PHC	SHO PHO	S/P

P = Platform; S = Inflatable slide;
L = Cooperative motivation level;
H = Competitive motivation level;
C = Clear air; O = Theatrical smoke;
S/P = Individual slide / platform option

Apparatus: The ACEF was configured as a B-737, with rows of triple seat assemblies placed 6-abreast in the cabin, and raised to a doorsill height of 8 feet 9 inches above the ground. A Type-I exit located forward of all seats was fitted with an inflatable single lane slide attached to the exit threshold by a typical girt bar. Foam-rubber tumbling pads were placed on a net directly underneath, and on the ground around, the slide to protect against injury from inadvertent falls (see Figure 1).

Across the aisle, another Type-I exit provided egress onto a 20 foot-square doorsill-height platform scaffold, which transitioned to the ground via a 10 foot wide, 35 foot-long ramp extending from the platform directly perpendicular to the exit and inclined at 15 degrees (see Figure 2). Both exits were covered with fabric "doors" that were removed by a research team member immediately upon the start buzzer sounding at the beginning of each trial. This was intended to preclude door-opening activities from being a confound.

Video cameras with timing capability were situated parallel to the fuselage at the exits to archive the evacuation data. Two smoke generators provided theatrical smoke for the obscured-visibility trials. During trials the ACEF was maintained at the CFR § 25.812 minimum 0.05 foot-candle emergency interior lighting level. Airline flight attendants were stationed at both Type-I doors to encourage passengers and assist them (if needed), and members of the research team were located at the end of the slide or inclined ramp to assist passengers and to guide them away from the area after they had deplaned. Medical personnel were in attendance in the event of injury.

Motivation: The base motivation level used in the study was provided prior to each trial during a briefing by the principal investigator. Passengers were reminded that the evacuation was intended to simulate an actual emergency, and that they should egress as fast as possible. Then at the start of each trial, the flight atten-

dant at the active door would shout commands to unbuckle seat belts and come forward to the exit. The flight attendant continued to shout evacuation commands and gesture enthusiastically throughout every trial.

Passengers in the lower motivation groups were also told to egress in an orderly fashion, i.e., without pushing, shoving, or impeding their neighbors. They were told this was to be a fast, but *cooperative*, evacuation.

The higher motivation level, i.e., *competitive* egress, was induced by instructing 2 of the groups that anyone in the group could earn a financial bonus of \$50.00 by being among

the first 25% of the passengers to evacuate the aircraft, as averaged across all 5 egress trials. This technique was designed to assure sustained competition among all subjects. (Their seating was rotated to allow equal opportunity.) Their briefings included no instructions to be orderly, but emphasized the financial reward for fast individual egress. Passengers asking about shoving, pushing, and jumping ahead in line (as occurred in both competitive groups), were told to use whatever effort or technique they felt necessary to egress rapidly, short of injuring themselves or others.

Figure 1

Slide Egress Route

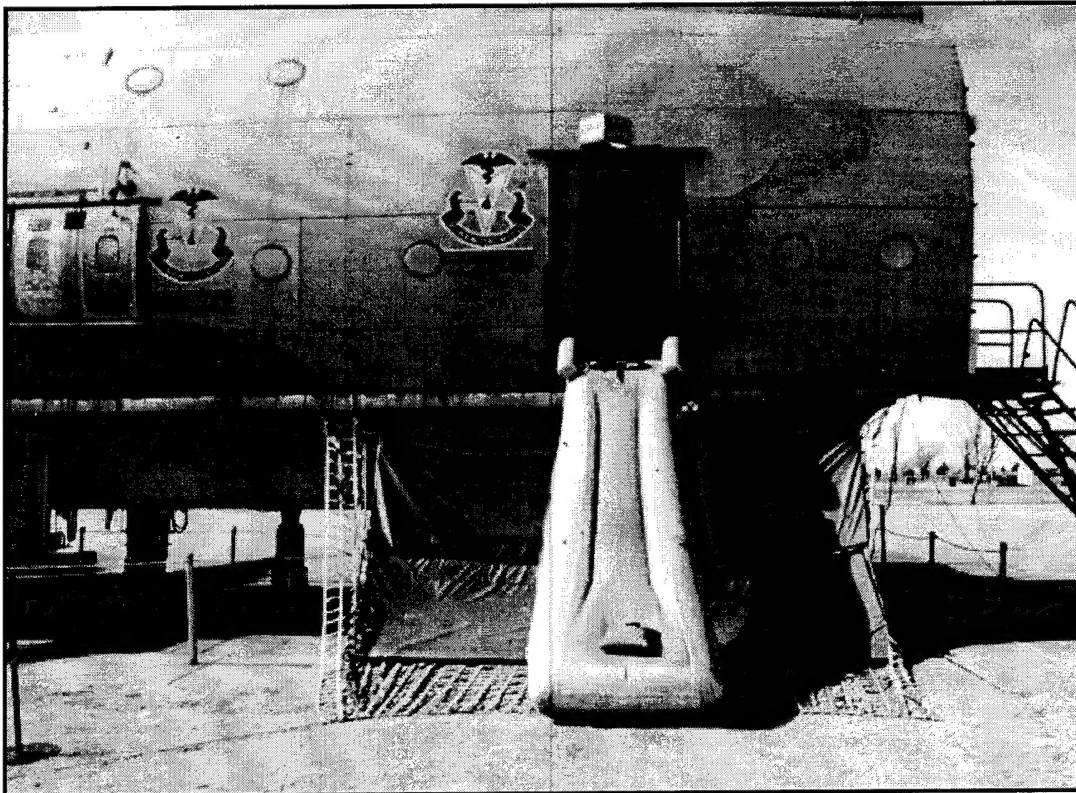
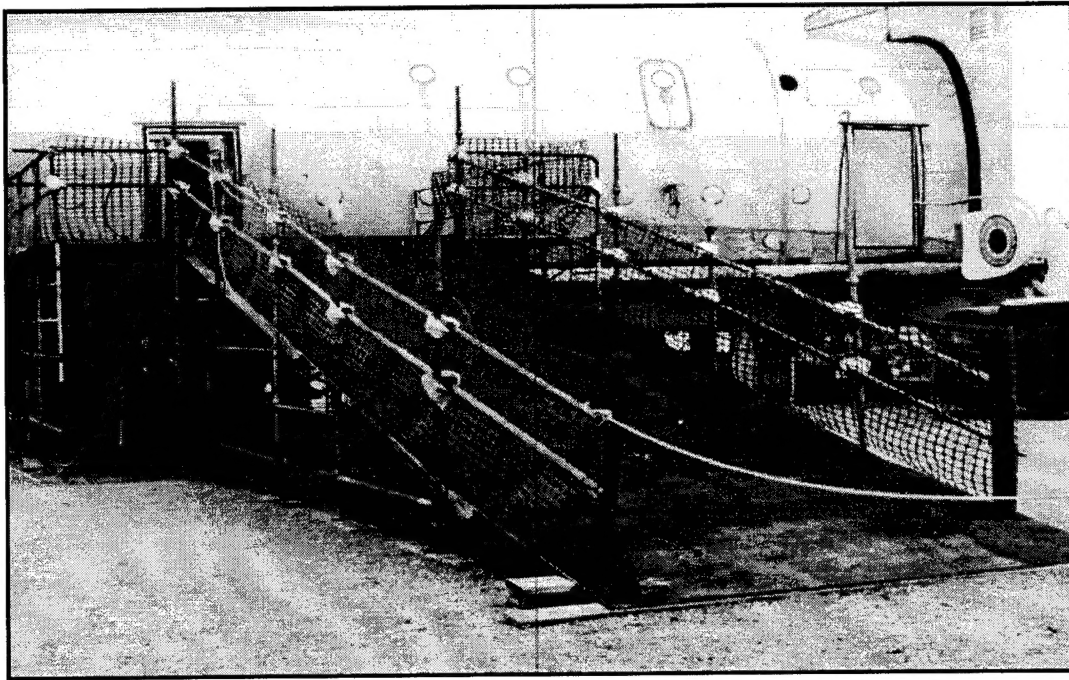


Figure 2
Platform Egress Route



Procedure: Prospective passengers were given a general explanation of the purpose of the study, detailed information about the procedures to be used, and provided visual information and briefings about how to use the inflatable escape slide. Afterward, they provided informed consent. Once entered into the study, subjects also completed a personal demographics questionnaire, the Jackson Personality Inventory®, and had their height, weight, and waist size recorded. They were then escorted to the ACEF to become visually familiar with the egress systems and prepare for the trials. The passengers were issued a boarding card with seat assignment, and they seated themselves accordingly. After the briefings describing the experiment were read, they were allowed to ask additional questions.

When these activities were completed and the passengers indicated their readiness, the principal investigator exited the cabin to avoid interference with the trial. The buzzer used to signal the beginning of the trial was sounded after some variable interval of 30 seconds or less, and also after introduction of smoke to an optical density of 0.5/foot (31% light transmission) on those trials conducted in smoke. Then the fabric covering was immediately removed from outside the exit. The flight attendant at the active exit began shouting and gesturing for the passengers to unbuckle their seatbelts and proceed through the active exit. The other flight attendant blocked the inactive exit and began to redirect any straying passengers to the active exit across the cabin. After the trial was completed, the passengers were regrouped to repeat these activities for the next trial.

RESULTS

The videotape recordings of each trial were examined to obtain total evacuation times and these were analyzed using *SPSS for Windows*[®], version 6. Total evacuation time was defined as beginning at the time the start buzzer initially sounded and lasting until the 58th passenger had cleared the Type-I exit opening. The last 1 or 2 passengers (depending on group) were omitted from the analysis to control for possible changes in performance related to their rearmost positions in the queues. A 3-way (egress route x air quality x motivation level) repeated-measures analysis of variance found a within-group main effect of egress route ($p < .012$; Figure 3) and a between-group main effect of motivation level

($p < .008$; Figure 4). No within-group main effect of air quality was found ($p < .45$; Figure 5). However, a hyper-additive interaction effect was found for air quality by egress route ($p < .03$; Figure 6); this effect appeared to result from the effects of passenger hesitation at the Type-I exit fitted with the slide. The motivation level by egress route ($p < .25$; Figure 7) and the air quality by motivation level ($p < .9$; Figure 8), interaction effects failed to achieve statistical significance. The air quality by motivation level by egress route interaction term was also insignificant ($p < .2$). These effects reveal the strong role that financial incentives and differences in egress route had on the evacuations, especially when related to passengers' ability to see.

Figure 3

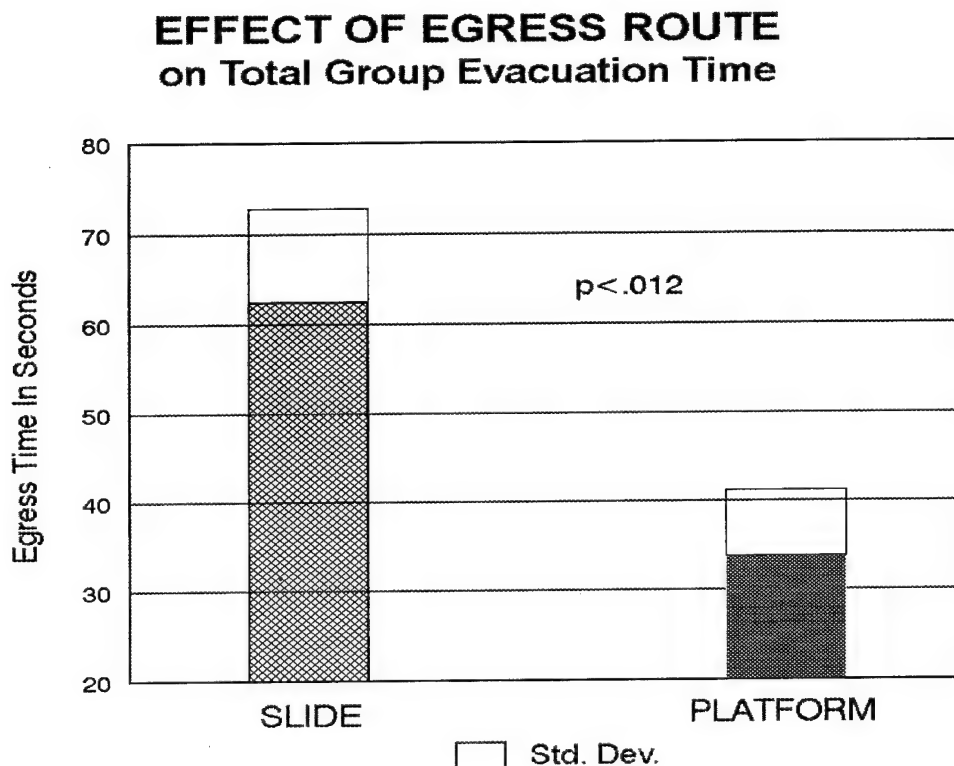


Figure 4

**EFFECT OF MOTIVATION LEVEL
on Total Group Evacuation Time**

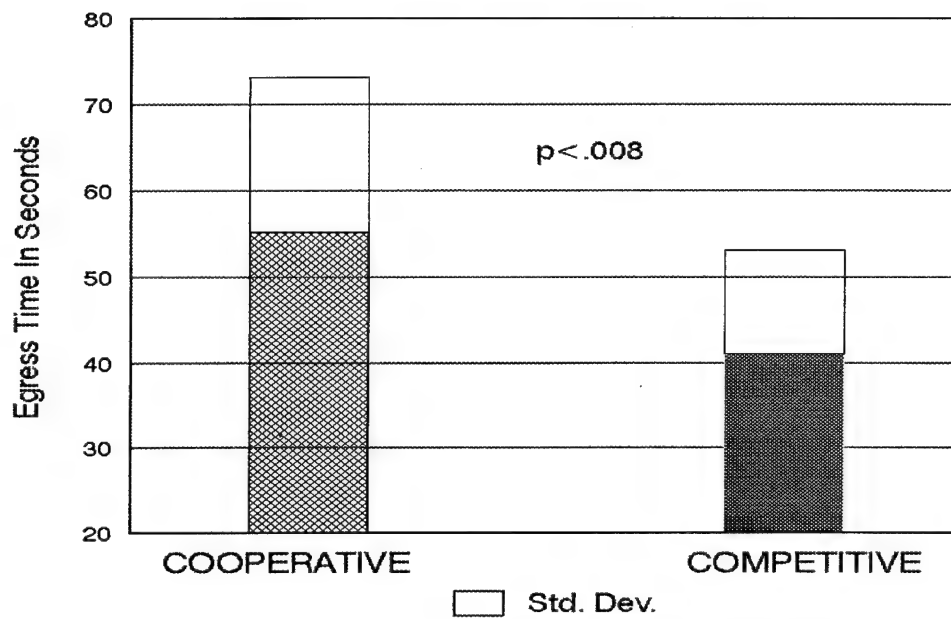


Figure 5

**EFFECT OF AIR QUALITY
on Total Group Evacuation Time**

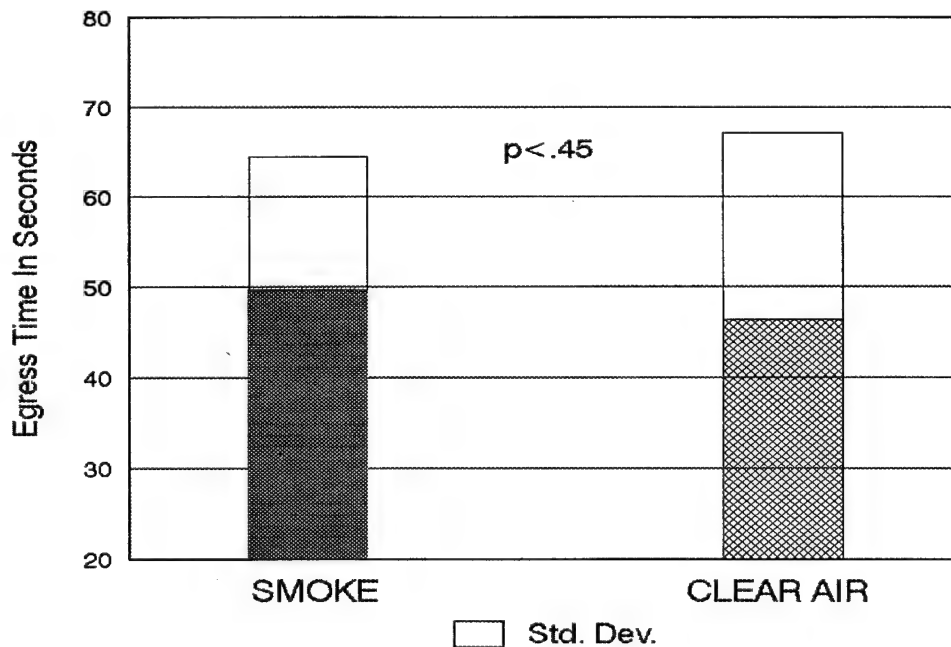


Figure 6

EFFECTS OF EGRESS ROUTE AND AIR QUALITY on Total Group Evacuation Time

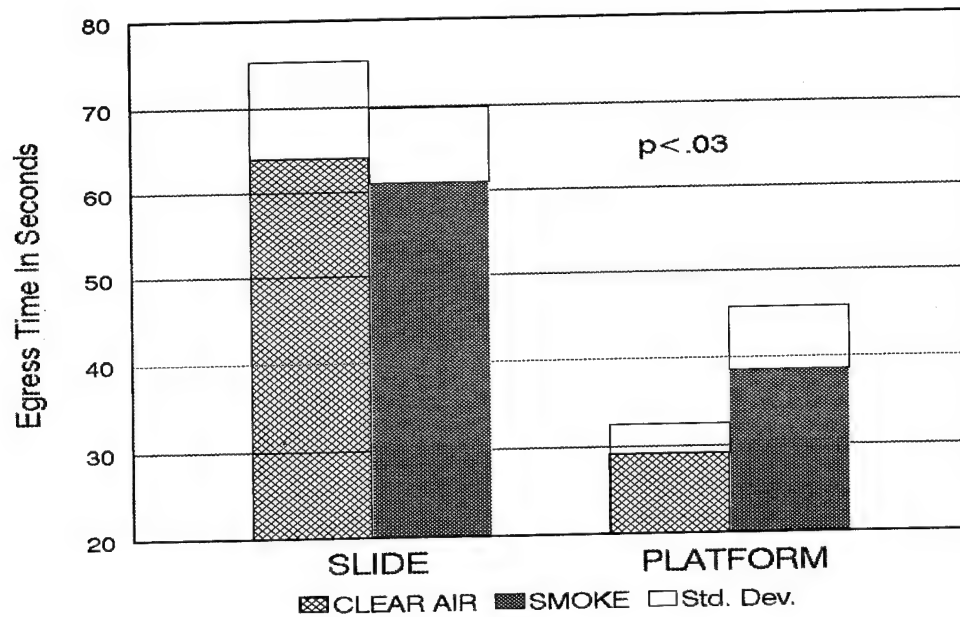


Figure 7

EFFECTS OF EGRESS ROUTE AND MOTIVATION LEVEL on Total Group Evacuation Time

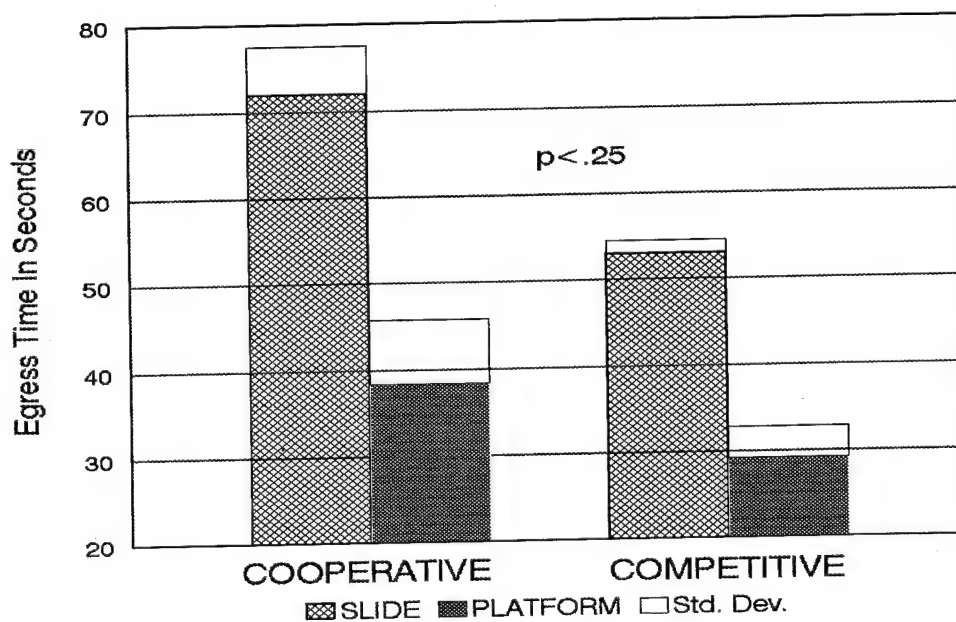
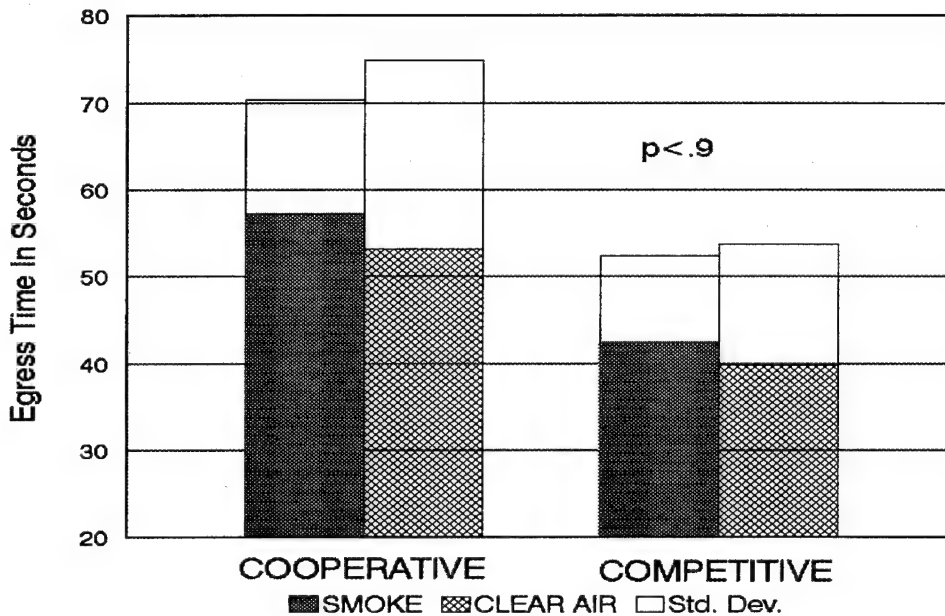


Figure 8

EFFECTS OF AIR QUALITY AND MOTIVATION LEVEL on Total Group Evacuation Time



DISCUSSION

These results attest to the potential for unanticipated findings from evacuation studies. Although typical results are likely to be found in most situations, when a single treatment is applied in novel designs, or when multiple treatments are paired in novel ways, other, unanticipated findings should not be surprising.

Specifically, the effects of egress route on evacuation rates were shown to be significant, as the platform allowed much faster evacuations than the inflatable slide. Passenger hesitation at the exit fitted with the slide was the governing principle for this effect, as egress onto the platform was essentially equivalent to going through a door from one room into another. There was no impediment to movement. In contrast, use of the slide re-

quired a downward leap onto the slide - this act required an associated leap of faith. Initially, the anxiety of having to jump onto the slide produced individual hesitations before passengers would jump; the cumulative hesitations are responsible for the main effect of egress route seen. The resultant implication for evacuation studies is that care must be taken to assure that any egress means chosen does not compromise the research question being addressed. In this regard it must be concluded that doorsill-height platforms do not model escape slides very well.

Similarly, studies purporting to model evacuations of specific aircraft should use the aircraft's actual means of egress to obtain the highest fidelity. In addition, typical exit opening size, doorsill height, escape slide descent angle, and emergency lighting systems (when appropriate) should be considered as well.

The use of air quality manipulations, such as smoke, to reduce visibility should also be carefully controlled, as the typical effects of significantly-delayed evacuations through Type-III exits produced by smoke were not found to occur here. This failure to find an effect of smoke on egress speed could have been produced because: 1) egress through floor-level exits is not as susceptible to the effects of reduced visibility as when using the Type-III overwing exit; 2) since trials in smoke always followed those in clear air, passengers were able to learn about the cabin layout and find their way to the exit more easily; or 3) the effects of one or more of the other treatments concealed the effects of the smoke.

The character of the air quality by egress route interaction effect, although unexpected, gives the explanation. Returning to Figure 6, it can be seen that smoke had a rather large deleterious effect on egress speed onto the platform, but it was shown to be ineffective, even appearing facilitative, for egress onto the slide. This latter effect, by itself, would be implausible, but because the smoke trials always followed the clear air trials, passengers seem to have benefitted from the earlier experience with the slide. As the situations were identical except for use of the slide or platform, this experience appears to be related to passengers' initial hesitation in using the slide and their subsequently increased willingness to jump onto it after their previous experience. This effect would decrease the individual hesitation times, and improve total group evacuation times. However, the decrease in hesitation times produced by the experience would have apparent limits as passengers also had to prepare themselves motorically to jump, and they typically waited for prior "jumpers" to clear the top of the slide before proceeding. Thus, while the platform results in smoke indicated slowed in-cabin movement by the passengers, the slide results suggest that the still larger delay produced by passenger

queuing at the slide masked the smoke-induced slowdown. Hence, in spite of the slowed egress produced by smoke, experience in using the slide allowed faster evacuations.

This indicates that the use of air quality (visibility) manipulations in studies employing floor level exits, especially in repeated measures designs, should also be tightly controlled. Likewise, the demonstrated cumulative effects of evacuation experience must be considered in these research designs

Financial incentives were found to produce a large facilitatory effect on evacuation speed, although motivation interacted with neither air quality nor egress route. Figure 7 shows that in the cooperative condition, when the flight attendant was the primary influence, passengers deplaned onto the slide at a typical rate of about 1.25 seconds per passenger. Egress rates onto the platform were nearly twice as fast, although passengers continued to maintain orderly use of the aisle as their sole in-cabin egress route. However, when the financial incentives were employed, the time for egress onto the slide decreased to 0.67 seconds per passenger, with a similar decrease for the time onto the platform. In addition, the variability among passenger egress times was also reduced for both egress routes.

These effects were produced by the competitive nature of the trials, and resulted from the passengers becoming more aggressive and climbing over seats, outmaneuvering other passengers, etc., to get out quickly. The fact that award of incentives was based on performance averaged across evacuation trials energized all passengers continually, maintaining the more competitive behaviors at high, consistent levels throughout the experimental sessions. This technique provided usable data from all passengers, enhancing the cost-benefit ratio of the study. Future studies desiring to manipulate passenger motivation levels could also benefit from this, or a similar, approach that assures sustained effort.

Figure 9

Cabin Interior After Competitive Trial



Figure 9 shows the broken-over seat backs typical of the cabin interior after a competitive trial; in contrast, all seat backs were always upright after the cooperative trials.

This effect parallels the effect of awarding financial incentives immediately after single egress trials through bulkheads found by Muir, et al. (1989;1992). However, these results are not comparable to the results they found with Type-III exits, where egress was significantly delayed by exit blockages produced by the passengers' expectations of financial rewards. The current finding also supports the argument made there by Muir: that significantly increased motivation impairs performance only when the exit opening is rather small.

The lack of an interaction of motivation level with egress route suggests that results acquired via motivational manipulations may

be less susceptible to confounds caused by techniques or apparatus that do not challenge passengers ergonomically. A corollary to this finding is that studies investigating egress behavior through floor-level exits (without significant restrictions) are likely not to benefit from the inclusion of financial incentives in the experimental protocol.

However, the human factors aspects of such studies may confound even the best intentions, especially where passengers are given some degree of latitude within the protocol. Recall that on the 5th trial of each series passengers were allowed to choose individually the egress route that they would use. In the competitive trials, a large majority (64%) of the passengers used the platform. Post-trial interviews revealed that all of the competitive passengers indicated later that they had chosen the egress route that ap-

peared to be the most accessible and would get them out the fastest. In contrast, cooperative passengers used the slide and platform in equal proportions; the passengers using the slide generally reported they chose it because it was more fun and more safe.

This reported perception of greater safety on the slide by the cooperative passengers appears inconsistent with the fact that the slide was much steeper and their descent much faster than the doorsill-height platform and ramp. In fact, the only significant injury (a broken ankle produced when a subject tried to slow her momentum near the bottom of the slide) occurred to one of the cooperative subjects who chose the slide on the 5th trial.

The apparent discrepancy between motivational groups in assessing the relative value of egress route is likely to have been caused by the specific motivators responsible for their respective performances. The competitive passengers were being controlled by the expectation of additional financial reward based on expedient egress; their behavior was consistent with this goal. The cooperative passengers, while being paid for their time, were motivated more in this choice condition by their own internal beliefs about the value of their participation in the study, their perceptions about the potential consequences of jumping onto the slide, and thus, their willingness to use the slide at all.

Given the actual risks involved in using an inflatable escape slide, such cognitive variables are likely to be internally inconsistent in regard to whether using the slide is personally acceptable. As persons are generally assumed to need internal consistency with regard to their attitudes, beliefs, and behaviors,

such situations are said to create a state of cognitive dissonance (see Festinger 1964; Brehm & Cohen, 1962). To restore internal consistency, persons must either modify their behavior, or distort internal or external reality to justify making the "correct" decision, (Zimbardo, 1969). Thus, the reports of greater safety and fun by the cooperative passengers choosing the slide may, in fact, be thought of as attempts to validate their chosen behavior.

In studies where the research question involves only a single condition, such effects should not create problems. However, in studies where questions, such as utilization of multiple exits, are being examined, strict control of the protocol and the passengers' expectations will be required to assure that the experimental question being addressed is the one being answered.

Thus, the potential for unexpected, and sometimes conflicting, results in evacuation studies is readily apparent. In consideration, the design of evacuation studies should include careful assessments of all relevant variables, including the aircraft structures and equipment, crew procedures, passenger attributes, and experimental treatments. Care should also be taken not to rely heavily on assumptions derived from similar, but untested, techniques, without some measure of the differences in effects that the experimental techniques can produce. Appeal to relevant research findings from other domains may be required.

Comparative studies done in independent laboratories, or when using multiple apparatus, appear particularly susceptible to such potential confounds, and only through significant attention to detail will the meaning of results be made clear.

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